

**EFFECTS OF RESONANT MAGNETIC FIELDS ON
CHICK FEMORAL DEVELOPMENT *IN VITRO***

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ABSTRACT

To assess the possibility that specific ionic resonances can influence bone development, 8-day chick femoral rudiments were explanted to lens paper rafts in BGJ_b medium and exposed for 1/2 hr/day to combined 16 or 80 Hz, 2×10^{-5} T (Tesla) peak sinusoidal and various static magnetic fields tuned to calcium, magnesium, potassium (16 Hz), and combined Ca/Mg (80 Hz) ion cyclotron resonances (CR) for 7 days. Ca/Mg tuned cultures were also exposed to 24, 4, 1, and 1/2 hr/day regimes to test for dose-response. Tuning for Ca, Mg, or Ca/Mg increased rudiment length and mid-shaft diameter, diaphyseal collar length

1 Address to which reprint requests should be directed

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and mid-shaft thickness, and reduced the gross L/D and diaphyseal L/T ratios, indicating greater robustness. Tuning for K produced exactly opposite results. There was no increase in effect if stimulation was increased beyond 1 hr/day for Ca/Mg combined tuning. These experiments indicate a significant effect of CR tuning on bone development *in vitro*.

INTRODUCTION:

From classical physics, one can determine for any ion a cyclotron resonance (CR) frequency when that ion is subjected to combined ac and static magnetic fields. Simply put, the resonance frequency is $2 f_c = (q/m)(B)$, where:

f_c = resonance frequency

m = mass of the ion in Kg

q = charge on the ion in coulombs

B = static magnetic field in T (1 Tesla = 1×10^4 Gauss)

We have suggested in the past that a cyclotron resonance mechanism may be utilized to couple to ions in channels, and thus mediate their passage through membranes, influencing a variety of physiological processes (1). If one examines the f_c/B ratios of various ions at the fundamental and odd harmonic frequencies which might be effective in CR, there are some degeneracies in the "code" which may allow common coupling to more than one ion simultaneously. An example of this is the fifth harmonic for calcium (ratio = 382.8 Hz/Gauss) which is quite close to the third harmonic for magnesium (ratio = 378.5 Hz/Gauss).

Our previous experiments (2,3) on the motility of diatoms, and theoretical considerations (1,4,5) suggested that combined ac and static magnetic fields tuned for particular ions could have other physiologically significant effects in multicellular organisms, specifically; changes in development. In addition, some of the diatom experiments suggested (6) that there may be a dose-response relationship, depending upon both the amplitude and length of exposure to the applied fields.

Accordingly, we chose to apply CR fields which were "tuned" to calcium, magnesium, potassium, and calcium/magnesium simultaneously to 8-day chick femurs explanted to organ cultures. As may be seen from the details which follow, these experiments strongly suggested that CR tuning may significantly affect the processes of development, advancing or delaying both enlargement of the femoral rudiments and ossification of their diaphyseal collars.

MATERIALS AND METHODS:

I. CULTURE METHODS;

Thirty-six eggs of adult white leghorn chickens were obtained from the University of Kentucky research flock at weekly intervals. They were placed in an incubator at approximately 2:00 P.M. on day 0. They were allowed to develop at 39° C for 7 days. On the morning of the 8th day, at approximately 9:00 A.M., the eggs were opened and the embryos were removed to sterile plastic petri dishes (150 mm, Falcon Plastics). Any abnormal embryos were discarded, as were those not sufficiently advanced. Only those embryos showing early feather germ development (Hamburger and Hamilton Stages 32-33) were used. Selection of this staging was made to facilitate femoral removal. At this stage, the femoral rudiments are sufficiently chondrified to withstand gentle handling, but the surrounding connective tissue is not strong enough to prevent easy removal of the head from the developing acetabulum.

The embryos were decapitated and placed ventral surface down in sterile plastic petri dishes containing Hanks' Balanced Salt Solution (HBSS), pH 7.4 (GIBCO). The femoral rudiments were then gently removed by blunt dissection with sterile instruments and placed in left-right pairs on pads of HBSS-moistened gauze in a second sterile petri dish. Twelve matched right-left pairs were obtained for each run. The pairs were then moved to dry sterile unbleached muslin pads and rolled gently back and forth to remove adherent tissues. This process, if carefully done, removes soft tissues without disturbing the periosteum or perichondrium. If either of these membranes is damaged, the rudiments will not develop normally; the cartilage cells and matrix are extruded through the defect and distort the rudiment. Any such rudiments and their pair members were discarded at analysis.

The left and right rudiments were then removed to numbered wells of paired Linbro 12-well culture plates (Flow Laboratories). The wells each contained a sterile stainless steel mesh triangle supporting a washed and sterilized triangle of lens paper. After placement of the femur in the center of the lens paper, the wells were filled with sterile Fitton-Jackson BGJ₁ medium (GIBCO) containing 1 ml GIBCO antibiotic/antimycotic solution/100 ml until the meniscus just covered the rudiments. This filling arrangement ensured adequate gas exchange for the cultured rudiments. The arrangement can be seen in Figure 1. This culture method is conceptually similar to that of Watson *et. al.* (7). No serum was added. The lack of serum reduced the growth rate of the rudiments, but helped to remove the

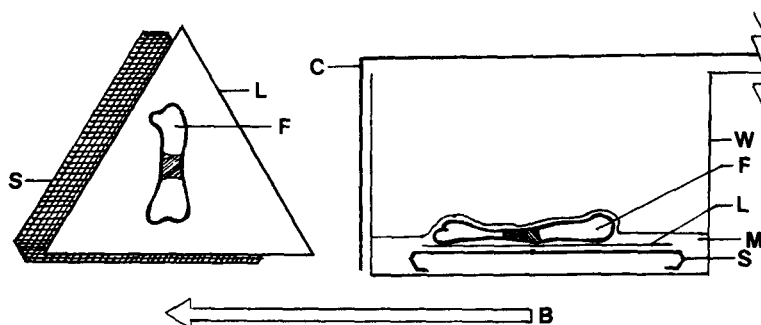


Figure 1. Femoral Rudiment Culture:

B = Flux Axis for Static and AC Magnetic Fields

C = Cover of 12-Well Plate

F = Femoral Rudiment (Stage 32-33)

L = Lens Paper Raft

M = BGJ_b Medium

S = Stainless Steel Mesh Raft Support

uncertainties caused by varying amounts of growth factors, bound ions, etc. present in different batches of serum. As the results will demonstrate, the rudiments did indeed continue to grow and add bone. As soon as the wells of each plate were filled, the cultures were removed to an incubator containing 5% CO₂ in 100% humidified air at 37° C. The medium was changed every other day. The plates containing left femurs were used as controls, while those containing the right halves of the pairs were exposed to the fields for 7 days. At the end of the experiment, the wells were emptied of medium, then filled with cold (4° C) 10% neutral buffered formalin solution and held for 24 hours.

II. EXPOSURE TO MAGNETIC FIELDS;

The plates to be exposed were removed to a portion of the incubator containing a plexiglass support holding paired 18 cm diameter Helmholtz-aiding coils consisting of 400 turns of no. 26 AWG magnet wire. The plates rested on blocks of styrofoam, and the coils

were arranged to pass magnetic fields parallel to the top and bottom of the plate (horizontally) and to the lens paper rafts. The device details have been published previously (2). No attempt was made to align the axis of the rudiments with the field axis. Exposures were accomplished by attaching the coils to Beckman FG2 Function generators. The fields were checked with a Beckman UC10 frequency counter, Schonstedt 2220 S-5 single-axis fluxgate magnetometer, and Tektronix 502A dual-beam oscilloscope, all of which were recalibrated prior to the experiments.

All exposures for single ions occurred at 16 Hz, with the peak ac field 2×10^{-5} T (400 mG). A dc field producing the appropriate resonance conditions was applied parallel to the ac field. For Ca^{++} ions, it was 2.09×10^{-5} T; for Mg^{++} , 1.27×10^{-5} T; and for K^{+} , 4.09×10^{-5} T. For the combined Ca/Mg resonance, the static field was set at 2.09×10^{-5} T, and the ac field was set at 80 Hz and 2×10^{-5} T peak. This corresponds exactly to the fifth harmonic for calcium ions, and very nearly the third harmonic for magnesium (79.1 Hz). The field was applied for 1/2 hr/day, from 9:00 A.M. until 9:30 A.M. each day for seven consecutive days.

For the dose-response measurements, the settings for Ca/Mg were used, and the field was turned on at 9:00 A.M. The field was turned off after 1/2, 1, or 4 hours, or left on continuously for the 24 hour exposures.

Controls were kept on the same shelf in the culture incubator as the experimentals, to ensure temperature and gas flow equality, but were positioned far enough from the stimulator coils that the ac fields at the control position were at least 4 orders of magnitude lower than in the treatment zone. In addition, since the static field was not adjusted in the control position, CR parameters were not maintained for any of the experimentally selected conditions.

III. DATA COLLECTION;

Every experiment entailed studying 24 pairs of femoral rudiments, performed as two consecutive runs. The length and mid-shaft diameters of the rudiments were measured after the rudiments had been in formalin for 24 hours (to ensure reasonably uniform shrinkage) using a vernier caliper and measuring to the nearest 0.1 mm. The rudiments were then

decalcified, dehydrated, soaked in sodium salicylate (oil of Wintergreen) for 12 hr, then embedded in 52-54⁰ Paraplast (Fisher Scientific). Serial sections were cut at 8 microns, and the sections were then mounted on albumenized slides, deparaffinized, rehydrated, and stained with Delafield's Hematoxylin and Eosin. They were then coverslipped using Permount (Fisher Scientific) and stored flat on trays for 7 days prior to analysis.

Analysis consisted of determining the diaphyseal collar length and mid-shaft thickness from mid-sagittal sections using an ocular micrometer. Length was measured to the nearest 0.01 mm, and the thickness to the nearest 0.001 mm.

The data were analyzed by Student's two-tailed t-test for matched paired samples, modified for small sample size ($n = 24$ for each sample). Statistical significance was considered to be obtained at $p < .05$. Bar graphs were constructed to illustrate the percent shift from experimental to control values.

RESULTS:

I. DISCRETE ION TUNING;

When the right and left femoral rudiments were compared at the beginning of each experiment, there were no significant differences between right and left bones. In fact, in very few cases, did the length vary by as much as 0.1 mm. However, the initial length and final control parameters varied considerably from experimental group to group, a variation which apparently depended upon the time of year the experiments were done. Rudiments cultured in winter and spring (Mg and K) were larger than those cultured in the summer and fall (Ca and Ca/Mg). Thus, control values certainly could not be pooled, and it appears important to run concurrent controls for any experiments of this type, if they are to be carried out over successive seasons. Given the standard deviations of the controls and experimentals, generally on the order of 10%, the use of the opposite side femurs as experimental/control pairs was judged to be appropriate. In any case, using any subject as its own experimental/control pair generally adds to the confidence in the validity of the results.

A. Gross Measurements: The results of the tuning for discrete ions at 1/2 hr/day are presented in Table I for gross measurements and in Figures 2 for parametric measurements

TABLE I
CHICK FEMORAL RUDIMENTS
EFFECT OF DISCRETE IONIC TUNINGS
ON GROSS BONE PARAMETERS
0.5 HOUR/DAY EXPOSURE

ION		n	L	D	L/D
Ca ⁺⁺	C	24	7.9/0.7	0.7/.06	12/0.6
	E	24	8.1/0.9*	0.9/0.8	9.3/0.5
K+	C	24	8.3/0.6	0.7/0.5	12/0.8
	E	24	7.0/0.5	0.7/0.6*	11/0.9**
Mg ⁺⁺	C	24	8.3/0.7	0.7/0.9	12/0.9
	E	24	9.0/0.7	1.0/0.1	9.3/0.6

L=Length D=Diameter at Mid-Shaft L/D=Aspect Ratio

Parametric values in millimeters: Mean/S.D.

*N.S.

** p<.01

All Other Experimental Values Significant at p<.001

and 3 for aspect ratios. Tuning for calcium ions clearly increased gross mid-shaft diameter (+29%, p<.001). However, the slight increase in gross bone length (+2.5%) was not significant at p<.05. Tuning for Ca strongly reduced the L/D ratio (-19%, p<.001), indicating that the bones were more robust (thicker in relationship to length). When magnesium ions were selected, both length (+8.4%) and diameter (+42%) were increased significantly (p<.001), though diameter increased relatively more than length, producing very large, robust rudiments (L/D -20%, p<.001). Potassium, on the other hand, appeared to inhibit lengthening of the rudiments quite markedly (-16%, p<.001). Since diameter did not increase at all, the result was an apparent increase in robustness (L/D, - 6.8%) which was significant at p<.01. The bones treated with potassium CR tuning appeared just visibly smaller than the others.

B. Microscopic Measurements: When we microscopically examined the diaphyseal bony collars, the differences caused by the CR tuning were striking. The data are presented in Table II, and in Figures 2 and 3, as above. Both calcium and magnesium ion tuning strongly stimulated diaphyseal collar ossification. The collars were longer (+45. and +48%, p<.001)

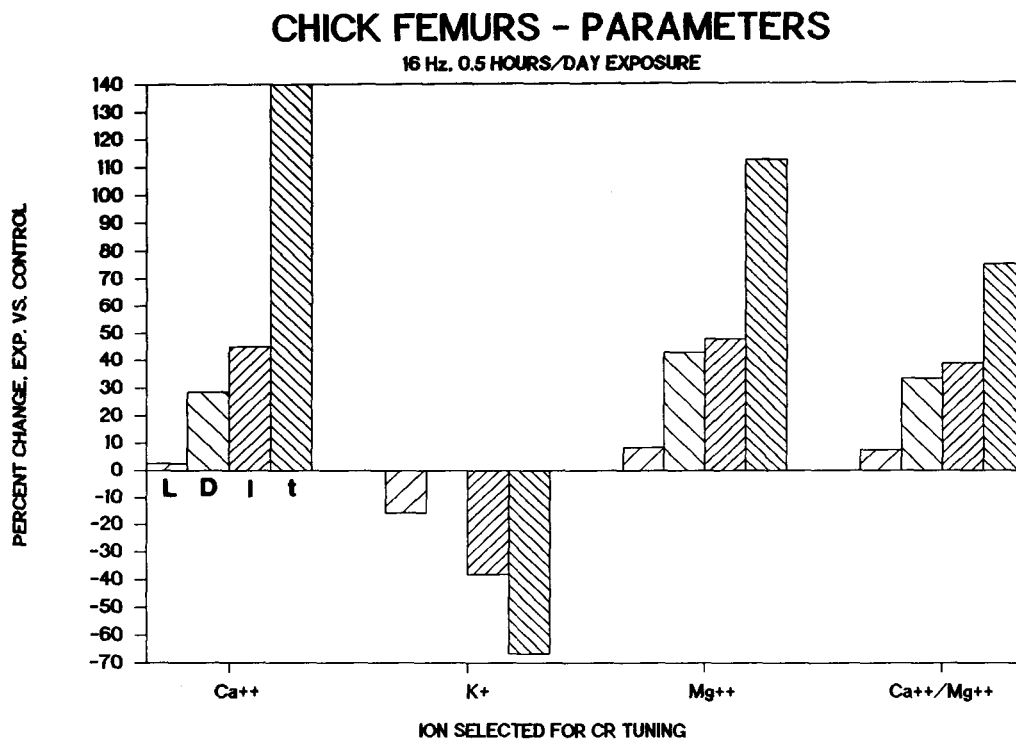


Figure 2. Percent Shift, Experimental vs. Control: Discrete Ion Tuning, Gross Parametric Measurements - Exposure; 1/2 per day to CR tuning for Ca⁺⁺, Mg⁺⁺, K⁺, and combined Ca⁺⁺/Mg⁺⁺.

L = Gross Femur Length

D = Gross Femur Diameter

l = Diaphyseal Collar Length

t = Diaphyseal Collar Thickness

and thicker (+140 and + 113%, $p < .001$) than their control pairs. Thickness was again relatively more strongly influenced than length, leading to lower L/T ratios (-41 and -29%) and thus more robust collars ($P < .001$). In contrast, tuning for potassium ions very strongly inhibited ossification. The collars were shorter (-38%, $p < .001$) and thinner (-67%, $P < .001$) than their controls. The thinning was more marked than the shortening, leading to

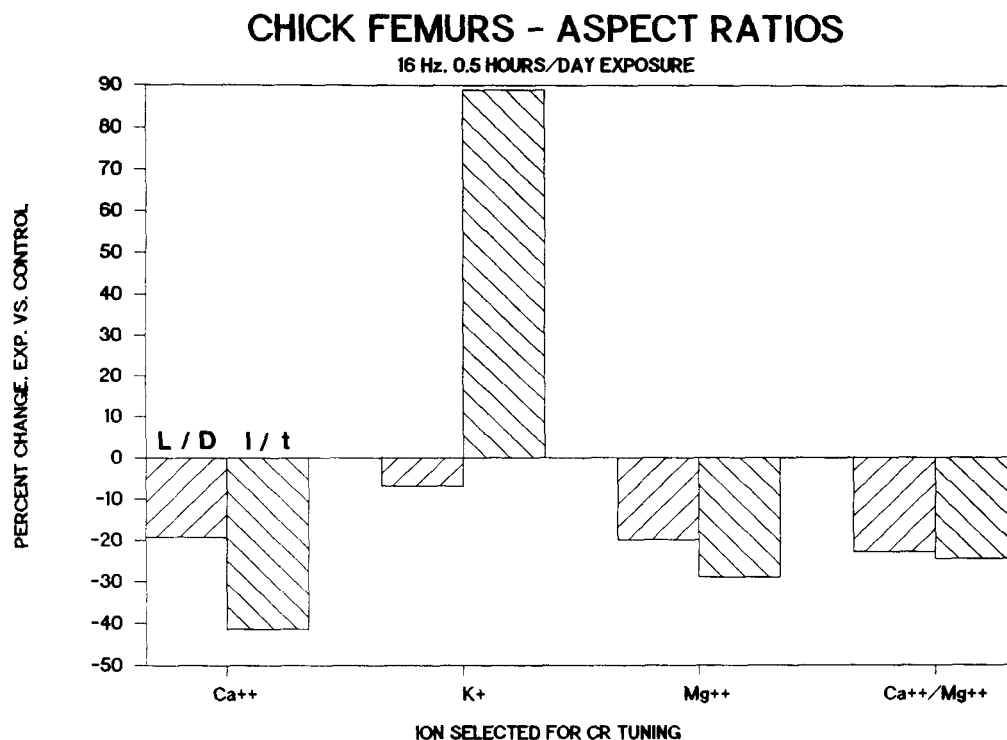


Figure 3. Percent Shift, Experimental vs. Control: Discrete Ion Tuning,

Aspect Ratio Calculations

L/D = Gross Length vs. Mid-Shaft Diameter

l/t = Diaphyseal Collar Length vs. Thickness

a remarkable increase in the L/T ratio (+89%, $p < .001$). The diaphyseal collars of these femora were very thin and fragile.

The figures illustrate the striking relative changes quite clearly. The reversal of the Ca-Mg and K effects is particularly obvious. Where the change is positive for Ca or Mg, it is generally negative for K, and *vice versa*.

II. HARMONIC TUNING;

A. Gross Measurements: When the frequency was increased to 80 Hz, with B remaining at 2.09×10^{-5} T, producing jointly the exact fifth harmonic for calcium and nearly the third

Table II

CHICK FEMORAL RUDIMENTS
EFFECT OF DISCRETE IONIC TUNINGS
ON DIAPHYSEAL COLLAR PARAMETERS
0.5 HOURS/DAY EXPOSURE

ION		n	L	T	L/T
Ca++	C	24	.40/.09	.005/.001	84/21
	E	24	.58/.08	.012/.003	49/7.2
K+	C	24	.50/.08	.009/.001	63/11
	E	24	.31/.12	.003/.002	119/44
Mg++	C	24	.44/.05	.008/.002	62/20
	E	24	.65/.15	.017/.004	44/14*

L=Bony Collar Length T=Bony Collar Thickness L/T=Aspect Ratio

Parametric Values in Millimeters: Mean/S.D.

*p<.01

All Other Experimental Values Significant at p<.001

TABLE III

CHICK FEMORAL RUDIMENT CULTURES
TIME VS. EFFECT

5/3 Ca/Mg TUNING
n=24 For All Data Points

PARAMETER (in mm)	CONDITION	24 Hr.	4 Hr.	1 Hr.	1/2 Hr.
Gross Length	Control	7.8/0.6	7.6/0.6	7.6/0.4	8.0/0.6
	Expt'l.	8.6/0.7	8.7/0.8	8.5/0.7	8.6/0.6
Gross Diameter	Control	0.7/.07	0.7/.04	0.7/.08	0.7/.08
	Expt'l.	0.9/.08	1.0/.05	0.9/.07	0.9/.07
Gross L/D	Control	11.2/1.2	10.8/1.1	11.3/0.7	11.9/1.1
	Expt'l.	9.5/0.8	9.1/1.0	9.2/0.5	9.2/0.5
Collar Length	Control	.75/0.14	.74/0.18	.72/0.16	.49/0.12
	Expt'l.	1.15/0.19	1.23/0.39	1.10/0.23	.68/0.13
Collar Thickness	Control	.012/.004	.012/.005	.011/.003	.008/.002
	Expt'l.	.028/.008	.030/.010	.029/.007	.014/.003
Collar L/T	Control	67.0/15.0	71.9/27.5	69.6/19.9	64.3/12.4
	Expt'l.	43.0/12.0	44.5/9.30	38.8/8.60	48.6/6.40

Number following slash (/) = Standard Deviaion

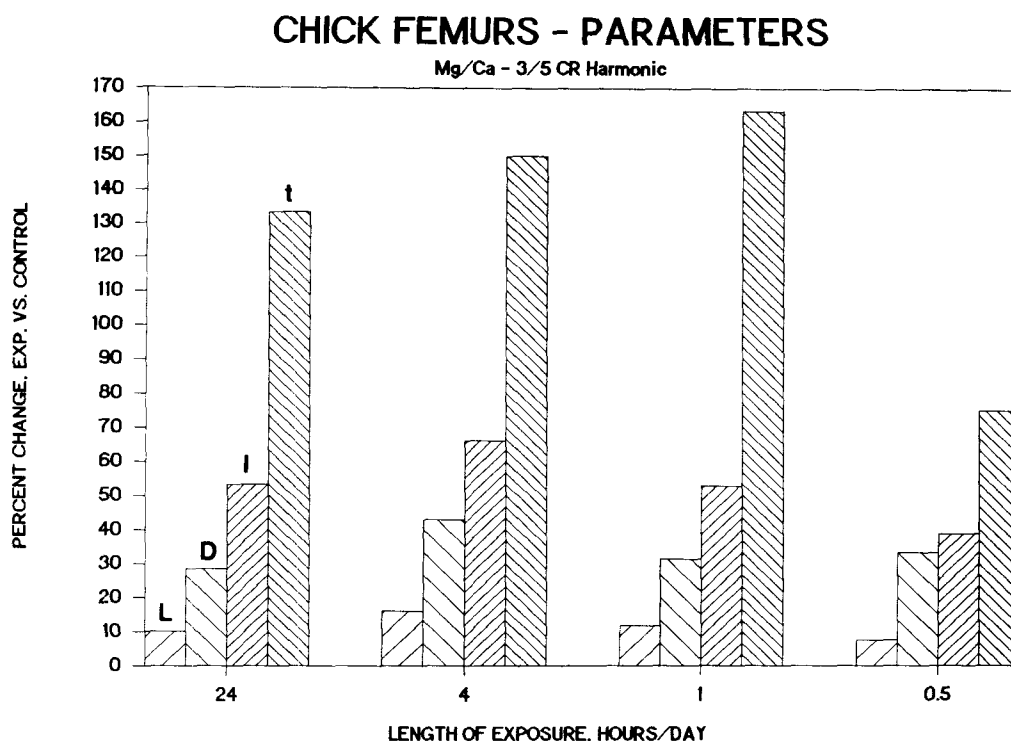


Figure 4. Percent Shift, Experimental vs. Control: 3n/5n Harmonic Tuning for Mg and Ca Ions Simultaneously, Gross Parametric Measurements

Exposure; 24, 4, 1, and 1/2 hr/day to CR tuning for combined $\text{Ca}^{++}/\text{Mg}^{++}$.

L = Gross Femur Length

D = Gross Femur Diameter

l = Diaphyseal Collar Length

t = Diaphyseal Collar Thickness

harmonic for magnesium, the femoral rudiments responded strongly again. With the exception of length, all values were different from their paired controls at $p < .001$, for the four periods per day (0.5, 1, 4, and 24 hours) the rudiments were exposed to the fields. Table III lists the results, and Figures 4 (for parameters) and 5 (for aspect ratios) illustrate the results. In general, the Ca/Mg tuning reproduced the effects of tuning for either ion alone. At 24, 4, and 1 hour, length was increased by +10, 16., and 12% respectively. These values

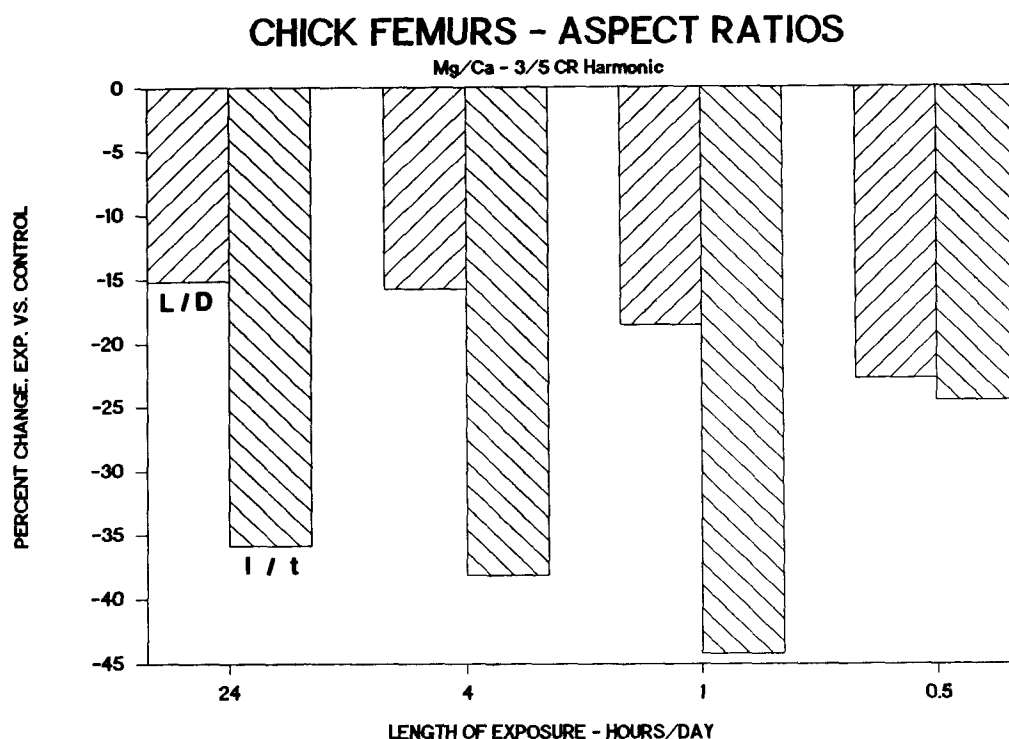


Figure 5. Percent Shift, Experimental vs. Control: 3n/5n Harmonic Tuning for Mg and Ca Ions Simultaneously, Aspect Ratio Calculations

L/D = Gross Length vs. Mid-Shaft Diameter

l/t = Diaphyseal Collar Length vs. Thickness

were significant at $p < .01$. At 1/2 hr/day, the increase was only +7.5% ($p < .05$), which compared closely with the increase using Mg alone (+8.4%), but not with calcium, which produced only a +2.5% change. Gross diameter increased +29, +43, +31, and +33% for exposures of 24, 4, 1, and 1/2 hour per day. The L/D ratios all decreased (-15, -16, -19, and -23%).

B. Microscopic Measurements: When these femora were examined microscopically, they again revealed that the stimuli were similar in effect to discrete tuning for calcium and magnesium alone. Again as exposure varied from 24 to 1/2 hour per day, diaphyseal collar length increased by 53, 66, 53, and 39% respectively ($p < .001$). Collar thickness was again

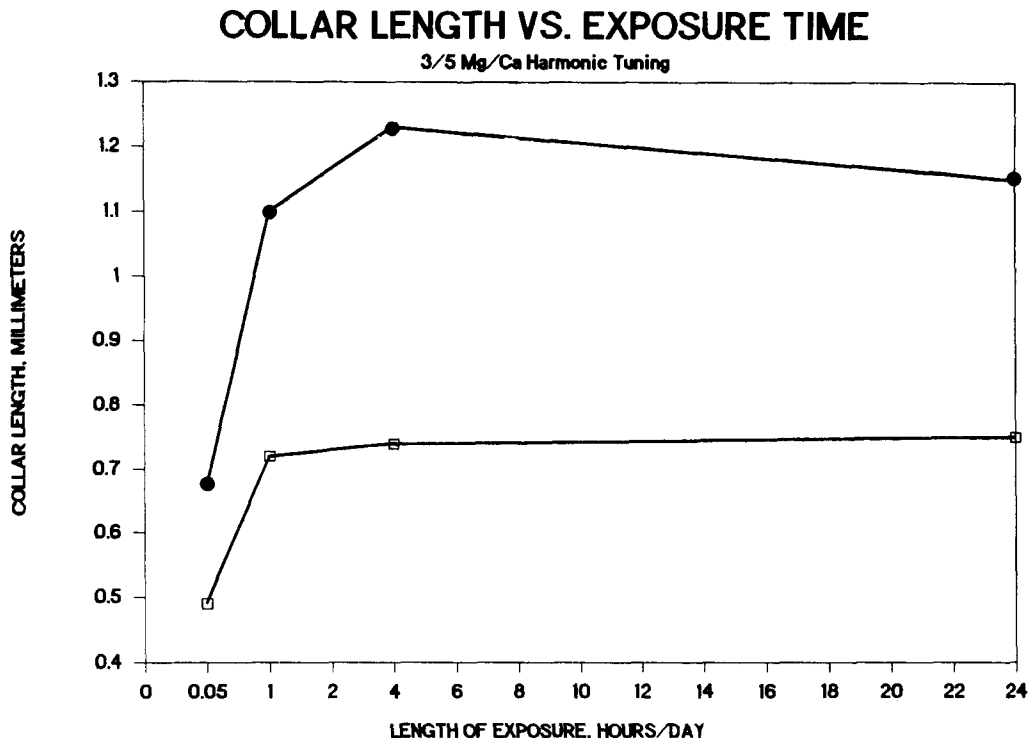


Figure 6. Diaphyseal Collar Length as a Function of Exposure Time, 3n/5n Harmonic Tuning for Mg and Ca Ions Simultaneously

Solid Circles = Exposed Femurs

Open Squares = Control Femurs

See text Table III for Standard Deviations. $p < .001$ for all values.

much more strongly enhanced, increasing by 133, 150, 164, and 75% as exposure time varied from 24 to 1/2 hour per day ($p < .001$). As would be obvious from the length and thickness data, the L/T ratios were strongly lowered, decreasing by 36, 38, 44, and 24% as exposure time decreased from 24 to 1/2 hr/day ($p < .001$).

The figures illustrate these percentage shifts graphically, and clearly shows that exposures of 1 or 4 hours per day seem to produce more marked results for most of the parameters than either 24 or 1/2 hour per day. Effects are obviously diminished at 1/2

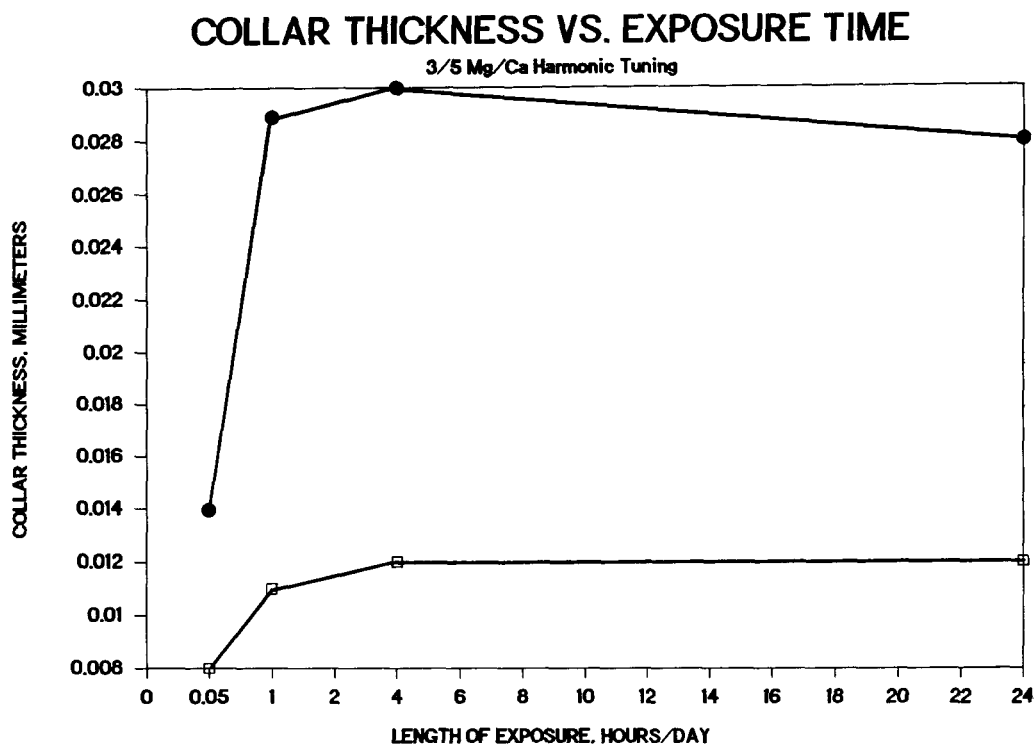


Figure 7. Diaphyseal Collar Thickness as a Function of Exposure Time, 3n/5n Harmonic Tuning for Mg and Ca Ions Simultaneously

Solid Circles = Exposed Femurs

Open Squares = Control Femurs

See text Table III for Standard Deviations. $p < .001$ for all values.

hour per day, as compared to the other exposure times, except for gross diameter and gross L/D, which are similar to the 1 hour data.

The most vivid demonstration of the overall effect of ionic resonance stimulation on the developmental process was seen in the changes in collar length and thickness. These are separately plotted as a function of exposure time in Figures 6 and 7. Note that the growth/time courses for exposed and control femora are similar in shape, but there is a marked, remarkably constant factor of enlargement, roughly 2.3 for the collar thickness and 1.5 for the collar length.

DISCUSSION:

When the magnetic field exposure conditions were set to satisfy calcium, magnesium, or combined calcium and magnesium harmonic tuning, it is clear that they stimulate femoral enlargement and ossification. Conversely, conditions satisfying CR tuning for potassium ions clearly are inhibitory. It is also interesting to note that stimulation for as little as 1/2 hour per day is adequate to produce marked effects, though 1 hour per day seems to be more effective. In addition, it would seem from these experiments that there is no particular advantage in stimulation lasting longer than 1 hour per day. We have not tested the lower limit for effectiveness, though if the rate of falloff of the effect is extrapolated, we would predict that a lower limit of about 15-20 minutes per day of stimulation will produce measurable results. We have no indication of the possible results if the duty cycles were differently dispersed, though there are some indications that it may be important, at least in experiments with tumor growth *in vivo* (8). Results which are basically similar to these were seen by Watson, et. al. (7), when 1 Hz, 1000 V cm⁻¹ square electrical pulses were applied transversely to dishes containing chick tibiae continuously for 9 days. Static fields were ineffective. Since square waves were used, a potentially large number of frequency componenets would have been present, and the static magnetic field was not measured. Hence, there is no way to assesss the possibilities of resonance. One can only state that ac electrical fields perpendicular to static magnetic fields would produce resonances in the same way as parallel magnetic fields.

For a discussion of the theoretical considerations of CR enhancement of trans-membrane ionic passage, the interested reader is directed to the theoretical papers cited in the introduction (1,4,5). Basically, our theory states that under appropriate conditions, the ac magnetic field couples to ions moving through a channel when the static field satisfies the cyclotron resonance formula. Other theories posit the action of the field at sites other than the ion channel core. Chiabrera, et. al. (9) suggest that the interaction occurs at the external membrane receptor site, while Lednev (10) suggests that the effects are essentially the result of gradual energy accumulation at calcium binding protein sites. In either case, resonance conditions are present as well. Most recently, using an analysis of electromagnetic forces in the channel where the parameters are expressed in cylindrical

coordinates, and assuming a channel structure revealed by recent high-energy electron microscopic examination (11), we believe that we can explain most of the results in diatoms, including the "windows" for frequency, harmonics, and ac field strength. Final confirmation awaits much more investigation and modelling effort. In any case, there have been both successes (12) and failures (13) in independent experiments testing the CR hypothesis.

Assuming that something ionic is going on in these experiments (and it has been shown that calcium channel blockers abolish cyclotron resonance field effects in other systems (14,15)), there is still the necessity of proposing some sort of physiological pathway. Magee *et. al.* have recently reported that harmonic tuning for Ca/Mg ions induces increases in the amount of alkaline phosphatase in bones of castrated male rats (16). However, it is a matter of opinion as to whether any specific enzyme such as alkaline phosphatase is the critical factor for change in the various resonance experiments that have been reported. The important observation in the present experiment is that when the apparent free intracellular concentrations of calcium, magnesium, or potassium ions are altered electromagnetically, truly striking changes in growth can occur. One can speculate that the complex of enzyme changes that are usually teased out in studying growth and development may be merely downstream factors secondary to the primary ionic determinants. Jackson and Bord (17) also report increased alkaline phosphatase activity and protein bound ^{45}Ca in femoral rudiments stimulated with sinusoidal fields at 15, 45, and 105 Hz, but not at 30 or 60 Hz. If resonance were involved, as it appears, these values represent n (15 Hz), $3n$, and $7n$ for the effective (odd) frequencies, and $2n$ and $4n$ for the ineffective (even) ones. Effectiveness of odd harmonics, but not even ones supports the CR hypothesis, though we have not seen results with $7n$ in diatoms (3). It would be interesting to see if Jackson could get positive results at 75Hz ($5n$). However, without static field measurements, it is impossible to certify what resonances were active in the Jackson experiments. From the F_c/B ratios, static geomagnetic field requirements would have been 1.96×10^{-5} T for calcium CR and 1.19×10^{-5} T for magnesium CR, values which could very well have existed in their laboratory, depending on the orientation of the coil axes with respect to the geomagnetic axes. If other laboratories working in the area of magnetic field effects would record the

static fields parallel to the axis of their coils, it would help to settle this question much more rapidly.

In any event, if ions are being moved across membranes by whatever mechanism, as seems probable (18), it is clear that the range of possible downstream effects on cell activity are so well documented for calcium and magnesium as to need no additional comment. Their role as cofactors and in second messenger activities is clearly established. Similar data are available for the suppressive actions of potassium ions. The often reciprocal effects of calcium and potassium ions are well documented. It has been suggested (5) in this context that the "opposite" results seen by different observers reporting on the calcium efflux from brain tissue, in which efflux is measured as well as influx, may result from inadvertent tuning to potassium as well as calcium ions. The implications of these experiments for clinical application of CR fields are also obvious; if CR tuned fields can influence bone growth and ossification, they ought to be useful in a variety of clinical settings where hard tissue formation or ossification needs to be enhanced or perhaps restrained.

Finally, we note the larger implication for development. The levels of static magnetic field employed in this work (1.27 , 2.09 , and 4.09×10^{-5} T) are quite representative of those found in the geomagnetic environment. There is the possibility that resonance effects similar to what we have observed *in vitro* may occur naturally during development; indeed may constitute an important factor. This hypothesis would be on firmer ground if it could be established that endogenous (electric field) oscillations are present in developing systems.

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